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Comparing energy balances, greenhouse gas balances and biodiversity impacts of contrasting farming systems with alternative land uses

H.L. Tuomisto [a,*], I.D. Hodge [b], P. Riordan [a], D.W. Macdonald [a]

[a] Wildlife Conservation Research Unit, University of Oxford, The Recanati-Kaplan Centre, Tubney House, Abingdon Road, Tubney, Oxon OX13 5QL, UK
[b] Department of Land Economy, University of Cambridge, Cambridge CB3 9EP, UK

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ABSTRACT

Life cycle assessment (LCA) is commonly used for comparing environmental impacts of contrasting farming systems. However, the interpretation of agricultural LCA studies may be flawed when the alternative land use options are not properly taken into account. This study compared energy and greenhouse gas (GHG) balances and biodiversity impacts of different farming systems by using LCA accompanied by an assessment of alternative land uses. Farm area and food product output were set equal across all of the farm models, and any land remaining available after the food crop production requirement had been met was assumed to be used for other purposes. Three different management options for that land area were compared: *Miscanthus* energy crop production, managed forest and natural forest. The results illustrate the significance of taking into account the alternative land use options and suggest that integrated farming systems have potential to improve the energy and GHG balances and biodiversity compared to both organic and conventional systems. Sensitivity analysis shows that the models are most sensitive for crop and biogas yields and for the nitrous oxide emission factors. This paper provides an approach that can be further developed for identifying land management systems that optimize food production and environmental benefits.

1. Introduction

Many studies have compared the environmental impacts of organic and conventional farming (Feber et al., 2007; Mondelaers et al., 2009; Williams et al., 2010). They show wide variation in the environmental impacts within both organic and conventional systems. Arguably, the greatest weakness of organic farming is its low yields, primarily resulting from lower levels of inputs, and higher abundances of pests and weeds (Köpke et al., 2008). Thus, organic farming requires more land for producing the same volume of output than conventional farming. Therefore, it is important to identify the specific practices that can provide environmental benefits and develop integrated farming systems that utilise those practices while maintaining relatively high levels of output per unit area.

Life cycle assessment (LCA) is commonly used for assessing environmental impacts of agricultural production (Nemecek et al., 2011; Stone et al., 2012; Thomassen et al., 2008; Williams et al., 2010). LCA uses a "cradle-to-grave" approach in accounting simultaneously for several environmental aspects of a product or service (ISO 14040, 2006). The impacts are allocated with respect to a unit of product termed the functional unit (FU). Generally agricultural LCAs use system boundaries from input production (e.g. fertilizers, pesticides and fuels) up to the farm gate and the FU is a unit of the agricultural product studied leaving the farm gate. Due to the complexity and high land use impacts of agricultural systems, agricultural LCAs face some specific challenges compared to industrial LCAs.

In agricultural LCA studies, there is scope for misinterpretations if the alternative land use options are not taken into account. Thus, some studies suggest that extensive farming systems are more environmentally sound than intensive systems (Cederberg, 1998; Hole et al., 2005). However, land is a limited resource for which there are always alternative potential uses. By definition extensive farming systems require more land to produce a given amount of product than do intensive systems. Extensive systems may have lower energy need per product unit due to low input use, but if the alternative land use options are taken into account, it may be found that the overall energy balance of the intensive system is more favourable (Berlin and Uhlin, 2004).

If only a fraction of the land used in an intensive system is needed to produce the same product output, the land saved can be utilized for other purposes, e.g. bioenergy production. Therefore, the intensive system might produce more energy than is needed for the production process and that excess energy could be used, for instance, to replace oil in heating, electricity production or transportation fuels. After taking account of the alternative land use options, the overall energy efficiency of the intensive farming

* Corresponding author. Tel.: +39 0332 786731; fax: +39 0332 785601.
E-mail address: htuomist@gmail.com (H.L. Tuomisto).

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system becomes more favourable. The opportunity cost principle in the context of agricultural land use has been introduced by Berlin and Uhlin (2004), who compared a system producing organic milk with a system producing conventional milk and willow for energy production.

The alternative land use options are also relevant when biodiversity conservation strategies are assessed. Many studies have shown that organic farms have higher level of biodiversity compared to conventional farms (Bengtsson et al., 2005; Hole et al., 2005). However, some attempts have been made to answer the question concerning whether extensive farming can provide higher benefits than intensive farming with land sparing (Fischer et al., 2008; Green et al., 2005; Phalan et al., 2011). Green et al. (2005) created a model to assess the trade-offs between wildlife friendly farming systems having lower levels of crop productivity and land sparing that minimizes the demand of farmland by increasing yields. Due to lack of data, they were not able to assess which of the systems is better for biodiversity in the developed countries. However, they suggested that in developing countries high-yield farming might lead to higher levels of biodiversity. Hodgson et al. (2010) used butterflies as an indicator of biodiversity and found that conventional cereal farming with nature reserves provides higher biodiversity benefits than organic farming when the organic crop yield is below 87% of conventional yield.

The aim of this study is to compare greenhouse gas (GHG) balances, energy balances, and biodiversity impacts of organic, conventional and integrated farming systems taking account of the alternative land use options. The impacts are compared both at the farming system and the farming practice level.

As the aim of the study is to compare different farming systems and practices, modelling and secondary data were chosen to be the most suitable tools for the analysis. Modelling enables the assessment of different types of farming practice combinations and does not limit the study only to existing systems. The use of secondary data based on average values also excludes biases that may occur when site-specific data are used.

The integrated farming systems were designed so as to combine the best practices for reducing environmental impact, including a versatile crop rotation, use of organic fertilisers, use of over winter cover crops, use of pesticides only when needed in order to avoid crop failures, integration of biogas production and recycling of nutrients. The models do not represent average integrated farming systems, but rather are designed to enable the comparison of the impacts of farming systems consisting of combinations of different farming practices. Therefore, this study does not provide information about the sustainability of the existing integrated farming systems, but aims at examining the impacts of different farming practices and systems on energy use, GHG emissions and biodiversity when alternative land use options are taken into account.

2. Materials and methods

2.1. Goal, scope, functional unit and system boundaries

LCA with an assessment of alternative land use options was used for comparing energy balances, GHG balances and biodiversity loss of model farming systems under organic, conventional and integrated management. The functional unit (FU) was food crop output of 460 t potatoes (t = tonne = 1000 kg), 88 t winter wheat, 60 t field beans and 66 t spring barley produced on a 100 ha (ha = hectare = 10,000 m^2) farm. These crop outputs were determined by the yield from a 20 ha of organic field available for each crop under a standard organic rotation in lowland farming in England. Higher yielding systems required less land for producing the FU and the land area not needed for production of the food crops for the FU and green manure crops to sustain fertility was available for alternative uses. Three alternative land uses for 'the rest-of-the-land' were included: cultivation of *Miscanthus* energy grass, managed forest and natural forest. In some of the systems biogas was produced from green manure, cover crops and straw. The energy produced from *Miscanthus*, wood and biogas was assumed to replace fossil fuels, and therefore treated as negative energy input and GHG emissions in the balance calculations.

The system boundaries included the production of farming inputs (e.g. fuels, fertilizers and pesticides), machinery, buildings and biogas production facility; field operations and crop cooling and drying. Soil nitrous oxide emissions were included in the study. The soil carbon emissions and sequestration were not taken into account, because net sequestration or emission only occurs when the soil management type has been changed until a new equilibrium level is reached. Energy inputs, greenhouse gas emissions and biodiversity impacts were calculated using Microsoft Excel spreadsheets.

2.2. Farming system models

The organic crop rotation was designed according to the recommendations for an arable organic farm that does not use external nitrogen inputs (Lampkin et al., 2008). The model organic crop rotation was thus designed to be self-sufficient in nitrogen, consisting of: (1) grass-clover (GC); (2) potatoes (*Solanium tuberosum*); (3) winter wheat (*Triticum aestivum*) + undersown overwinter cover crop (CC); (4) spring beans (*Vicia faba*) + CC; and (5) spring barley (*Hordeum vulgare*) + undersown GC.

The model farming systems compared were:

1. *Organic farm without biogas production (O)*. The GC, CC and crop residues (CR) were incorporated into the soil. Ploughing was used.
2. *Organic farm with biogas production (OB)*. Otherwise similar than O, but the GC, CC and CR (straw of wheat and bean crops) were harvested for biogas production and the digestate was spread to potatoes, winter wheat and spring barley. Ploughing was used.
3. *Conventional farm (C)*. Produced potatoes, winter wheat, spring beans and spring barley using mineral fertilizers and non-organic pesticides. The crop rotation did not include GC or CC, and biogas was not produced. Ploughing was used. Crop rotation consisted of potatoes, winter wheat, spring beans and spring barley.
4. *Integrated farm (IF)*. The crop rotation and biogas production were similar to the OB system, but non-organic pesticides were applied. Ploughing was used.
5. *Integrated Special (IFS)*. As IF but instead of GC municipal bio-waste was used as a fertilizer. Non-organic pesticides and no-tillage were used. Crop rotation consisted of potatoes, winter wheat, spring beans and spring barley.

2.3. Nutrient supply

The O, OB and IF systems were designed to be self-sufficient in nitrogen, whereas C and IFS systems used external inputs. C system is the only one that uses synthetic nitrogen fertilizers. IFS imports anaerobically treated food waste from human communities in order to close the nutrient cycle between fields and consumption. The nutrient inputs in the systems are presented in Table 1. In order to ensure the nitrogen supply in the O, IF and IFS systems, it was assumed that cover crops included nitrogen fixing species. Additional phosphorus (P) and potassium (K) were applied in all of the systems. P and K inputs in IFS systems were assumed to be half of the inputs in the C system as the other half were assumed to be retrieved from the organic materials imported. In the organic